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END OF SEARCH HISTORY

L7: Entry 6 of 7 File: USPT May 15, 2001

DOCUMENT-IDENTIFIER: US 6233515 B1
TITLE: Adaptive vehicle cruise control system and methodology

Abstract Text (1):
Disclosed herein is a headway control for an adaptive cruise control system based on a basic headway control law derived from feedback linearization techniques. The usefulness of the linear approximations is demonstrated, and basic attributes of data which are believed important to system response are introduced. Certain modifications to a basic headway controller for enabling system performance to better meet driver expectations under real road conditions are made as a result of empirical information.

Brief Summary Text (3):
This invention relates generally to adaptive cruise control systems for automotive vehicles, and more particularly to apparatus and methods for headway control.

Brief Summary Text (5):
An adaptive cruise control (ACC) system can enhance performance of vehicle speed control, also known as vehicle cruise control, by allowing a vehicle to actively track and follow a target vehicle while maintaining a follow distance that is proportional to the timed headway between the vehicles plus some minimum distance. The speed of the follow vehicle is controlled by controlling the application of acceleration force to the vehicle over a range spanning positive and negative accelerations.

Brief Summary Text (7):
Negative acceleration, sometimes called deceleration, may be applied to a vehicle via service brakes of the vehicle. In a vehicle that has hydraulic-actuated service brakes at wheels of the vehicle and an ABS system for operating the vehicle's service brakes, an adaptive cruise control may apply deceleration force to the vehicle via the ABS hydraulic system.

Brief Summary Text (8):
Various arrangements for adaptive cruise control are shown in various patents, including one or more of U.S. Pat. Nos. 5,053,979; 5,396,426; 5,400,864; 5,454,442; 5,493,302; 5,594,645; and 5,629,851.

Brief Summary Text (11):
Another general aspect relates to an automotive vehicle comprising: a powertrain comprising an engine having a throttle that is selectively operated to apply an acceleration force to the vehicle via wheels on which the vehicle is supported and propelled along an underlying surface; a vehicle speed control for selectively throttling the engine via the throttle to null discrepancy between actual vehicle speed and preset vehicle speed; range and range rate apparatus for providing range and range rate signals corresponding to range and range rate to an immediately preceding lead vehicle; and a headway controller that acts via the vehicle speed control for nulling discrepancy between range to the lead vehicle obtained by the ranging apparatus and a reference range that varies with timed headway; wherein the range and range rate apparatus and a vehicle speed sensor close feedback loops to the headway controller, and the headway controller function for accelerating and decelerating the vehicle is mathematically defined by a plane where range error is along one of two orthogonal axes and range rate is along the other of the axes by a

continuous control surface having plural distinct regions, a first region being a maximum acceleration region characterized exclusively by positive values of range rate, a second region being a maximum deceleration region characterized exclusively by negative values of range rate, a third region being a relatively more rigid control region, and a fourth region being a relatively less rigid control region, and wherein the first and second regions are noncontiguous and separated by the third and fourth regions, the third region has an expanse that, for negative values of range error within the third region, includes both positive and negative values of range rate, and for positive values of range error within the third region, includes positive, but excludes negative, values of range rate, and the fourth region has an expanse that, for negative values of range rate within the fourth region, includes both positive and negative values of range error, and for positive values of range rate within the fourth region, includes positive, but excludes negative, values of range error.

Brief Summary Text (12):
Still another general aspect relates to an automotive vehicle comprising: a powertrain comprising an engine having a throttle that is selectively operated to apply an acceleration force to the vehicle via wheels on which the vehicle is supported and propelled along an underlying surface; a vehicle speed control for selectively throttling the engine via the throttle to null discrepancy between actual vehicle speed and preset vehicle speed; range and range rate apparatus for providing range and range rate signals corresponding to range and range rate to an immediately preceding lead vehicle; a headway controller that is operable to different modes including an adaptive cruise control mode, that forms a portion of a closed-loop control wherein the range and range rate signals and a vehicle speed signal corresponding to actual vehicle speed provide closed loop feedback to the headway controller, and that develops a reference speed signal which provides a command signal input to the vehicle speed control for causing the vehicle speed control to null discrepancy between range to the lead vehicle as measured by the range signal and a reference range that varies with timed headway when the adaptive cruise control mode assumes a follow state; and upon losing the track of the lead vehicle while actual vehicle speed is less than preset speed, the headway controller is operable to transition from the follow state of the adaptive cruise control mode to a resume state of the adaptive cruise control mode to return vehicle speed toward preset vehicle speed as a function of lateral acceleration of the vehicle.

Drawing Description Text (3):
FIG. 1 is a block diagram of an adaptive cruise control system.

Drawing Description Text (4):
FIG. 2 is a reduced block diagram of the adaptive cruise control system of FIG. 1.

Detailed Description Text (2):
An adaptive cruise control (ACC) system can enhance performance of vehicle speed control, also known as vehicle cruise control, by allowing a vehicle to actively track and follow a target vehicle while maintaining a follow distance proportional to the timed headway, h, between the vehicles plus some minimum safety distance, d.sub.o, timed headway being defined as ##EQU1##

Detailed Description Text (5):
Negative acceleration, sometimes called deceleration, may be applied to a vehicle via service brakes of the vehicle. An actual implementation in any particular vehicle will depend on particular details of the vehicle's brake system. For example, in a vehicle that has hydraulic-actuated service brakes at wheels of the vehicle and an ABS system for operating the vehicle's service brakes, an adaptive cruise control may apply deceleration via the ABS hydraulic system.

Detailed Description Text (9):
The vehicle also has a service brake control 24, designated Brake Controller in FIG. 1, that acts to apply braking torque to the wheels via the vehicle's ABS hydraulics, hence applying deceleration force to the vehicle. The symbol P appearing in FIG. 1 represents hydraulic brake system pressure corresponding to braking force applied to the vehicle's wheels to decelerate the vehicle.

Detailed Description Text (10):
Attainment of a desired follow vehicle speed trajectory involves coordinated control over the selective operation of the engine throttle control to produce selective vehicle acceleration and over the selective operation of the service brakes to produce selective vehicle deceleration, while taking into account drag force acting on the vehicle. Speed controller 22 may be considered an acceleration function actuator, and brake controller 24, a deceleration function actuator. Collectively, such an acceleration function actuator and such a deceleration function actuator constitute a coordinated actuator for controlling the application of both acceleration and deceleration forces to the vehicle.

Detailed Description Text (12):
Certain aspects of the invention relate to a control system 32 shown in FIG. 2. Control system 32 has been derived as a reduced form of control system 20. Derivation of the reduced control system is premised on the presence of a coordinated actuator that provides a defined control range spanning both positive and negative accelerations and characterized by reasonably smooth switching between acceleration and deceleration function actuators (i.e. throttle control and brake control) whenever there is a transition from a positive acceleration to a negative one, and vice versa, such that a reference speed, vref, can be tracked.

Detailed Description Text (13):
The speed control and brake control systems are modeled herein as a linear first order system. While such modeling represents certain assumptions about overall system behavior, the model is believed suitable for the immediate present purpose. The use of vehicle speed as the controlled parameter that is controlled by the selective application of acceleration and deceleration forces, rather than the use of vehicle acceleration (positive and negative) as the controlled parameter, advantageously allows principles of the present invention to be incorporated into a vehicle that has an existing production cruise control system already imbedded in an existing engine management system (EMS) as the primary throttle actuator. This allows the inventive ACC system to take advantage of the existing throttle control diagnostics found in the EMS as well as allowing the headway control algorithm to be readily adapted to multiple powertrain configurations without the need to design at the level of detail required by direct throttle control.

Detailed Description Text (19):
and it is this control function that is incorporated in the inventive ACC, such as by embedding it in the EMS as an algorithm that can be invoked when the cruise control function is switched on by the vehicle driver. This equation represents the desired control action to achieve a follow vehicle tracking response with the above defined error dynamics. One can see that the control function utilizes both range and range rate information as well as a follow vehicle speed feedforward command to achieve the desired tracking response. It is the follow vehicle speed feedforward command, the first term of the equation, that is believed novel in the context of an ACC.

Detailed Description Text (24):
Control strategy in an actual test vehicle was chosen initially to reduce range error to zero as an inverse exponential function of time. The particular ACC system design was also chosen to mimic driver behavior in moderate traffic with the intent of extending the useful range of conventional cruise control. However, a number of different drivers of the test vehicle noticed certain response characteristics that included: uncomfortably high acceleration and deceleration; unnaturally aggressive headway control; and discontinuous control behavior during target acquire/drop sequence. One might therefore conclude that a control system which is more comfortable to the driver is a matter of human factors, at least to some extent. While it may be convenient to mathematically define the objective of the system as controlling to a timed headway, the possibility of different driver behaviors during certain real time events and of differing driver comfort levels may call for certain control modifications, although in general, the timed headway model seems to match driver behavior.

Detailed Description Text (25):
It was observed that many drivers attach importance to minimal control effort,

particularly during brake usage, and smoothness of response that may override the stated control objective. Such driver response was especially evident during transient traffic conditions, such as rapid lead vehicle accelerations or cut-in situations. As designed, the control system attempts only to minimize range error and does not consider driver tolerance to acceleration, deceleration and the desire for strict headway control.

Detailed Description Text (26):
As a first attempt to better capture driver behavior in the control system, a limit on the maximum change in reference speed per sample interval was put at about 1 m/s for acceleration and -2.6 m/s for deceleration. These limits were empirically derived and roughly translate to limiting the commanded throttle and brake usage during transient target conditions. Additionally, the headway tracking characteristics of the system were changed by allowing overshoot in the range error dynamics. Headway following characteristics can thereby be altered to give a more desirable control response with a desired percent overshoot that gives the driver the perception of a more "relaxed" follow behavior. Through testing it was found that drivers liked a rather "loose" or "relaxed" control behavior under steady state following or when overtaking a slower vehicle. Conversely, if the follow vehicle is too close, such as after a cut-in, drivers expect the system to be noticeably more aggressive in controlling headway so that the driver is confident that the system will back off to the desired headway.

Detailed Description Text (32):
Thus, in the portions of Regions I and III outside zone 40, the primary objective is to control, if possible, within the constraints of maximum acceleration or deceleration, or otherwise default out of follow control. In Region I, this means reverting back to conventional cruise control if the follow acceleration required to return to steady state exceeds some threshold. In Region III, the brakes can be applied only to some maximum value, beyond which it will be necessary for the driver to intervene. Ideally, Region II may be characterized by a "loose" headway controller that possesses some overshoot, and Region IV may be characterized by a more "rigid" headway coupling that gives the driver confidence in the system's ability to back off a lead vehicle that is too close.

Detailed Description Text (36):
When combined with the transient limits on acceleration and deceleration, the desired change to the speed reference signal per sample interval is thus given as: ##EQU5##

Detailed Description Text (39):
In moderately dense traffic situations, the ACC system will see many different targets which are moving in and out of the lane of interest. Therefore, the control system must react seamlessly to the acquiring and dropping of new targets by the radar. This function is largely handled by the transient limits for acceleration and deceleration set in the Change in Speed function of FIG. 4. However, a special case arises when the desired change in speed causes the system to saturate the acceleration of the follow vehicle in Region I. If the saturation is excessive, the control system decides to drop out of ACC mode and resume the set speed maintained in memory which was set by the driver upon entering ACC follow mode. This is very much analogous to pushing the Resume button on conventional cruise control. When in this mode, the control system ramps the commanded speed from the current speed to the set speed at a nominal rate of 1 m/s.sup.2. This is considerably less than the upper transient limit on acceleration implemented in the Change in Speed function and is intended to mimic an automatic push of the Resume button. Therefore, if the lead vehicle begins a rapid acceleration or exits the lane entirely, the ACC system will smoothly return the vehicle into a conventional cruise control mode without the excessive accelerations that otherwise might make the driver uncomfortable. This logic is controlled by four basic parameters which are evaluated by the control system: valid target from the radar; speed error from equation (28); current vehicle speed; and ACC set speed.

Detailed Description Text (40):
The basic control logic can be seen in FIG. 6. If there are no valid targets for the ACC system or the valid target requires excessive acceleration to maintain the

proper headway, the system defaults out to a conventional cruise control function with an automatic resume. vehicle is increasing. In such case the controller may cause the vehicle either to hold speed or to coast. This allows a return to headway control that is unaccompanied by speed changes which, it is believed, many drivers would consider excessive.

Detailed Description Text (46):
Upon losing the track of the lead vehicle while actual vehicle speed is less than preset speed, the headway controller is operable to transition from the follow state of the adaptive cruise control mode to a resume state of the adaptive cruise control mode to return vehicle speed toward preset vehicle speed as a function of lateral acceleration of the vehicle. The function depicted by FIG. 8 comprises: completely inhibiting return of the vehicle speed toward present speed for lateral acceleration exceeding a predetermined maximum magnitude, and attenuating gain of the resume function in an inverse relation to the magnitude of lateral acceleration once the lateral acceleration has exceeded a predetermined minimum magnitude.

Other Reference Publication (1):
Mayr, Intelligent Cruise Control for Vehicle Based ob Feed-back Linearization, Proceedings of the American Control Conference, US, New York, IEEE, Jun. 29, 1994, pp. 16-20, XP000515245, ISBN: 0-7803-1784-X.

Other Reference Publication (2):
Youcef-Toumi et al., The Application of Time Delay Control to an Intelligent Cruise Control System, Proceedings of the American Control Conference, US, New York, IEEE, Jun. 24, 1992, pp. 1743-1747, XP000343593, ISBN: 0-7803-0210-9.

CLAIMS:

2. An automotive vehicle as set forth in claim 1 in which the vehicle further comprises a brake control system that is selectively operated to apply a deceleration force to the vehicle wheels, and the speed reference signal also provides a command signal input to the brake control system.

4. An automotive vehicle as set forth in claim 3 in which the vehicle further comprises a brake control system that is selectively operated to apply a deceleration force to the vehicle wheels, and the speed reference signal also provides a command signal input to the brake control system.

5. An automotive vehicle as set forth in claim 4 in which for a first further set of values of said range error and said range rate, the maximum function is limited to a predetermined maximum acceleration, and for a second further set of values of said range error and said range rates the maximum function is limited to a predetermined maximum deceleration.

6. An automotive vehicle comprising:

a powertrain comprising an engine having a throttle that is selectively operated to apply an acceleration force to the vehicle via wheels on which the vehicle is supported and propelled along an underlying surface;

a vehicle speed control for selectively throttling the engine via the throttle to null discrepancy between actual vehicle speed and a reference vehicle speed;

a headway controller that is operable to different modes including an adaptive cruise control mode;

range and range rate apparatus for providing a range signal and a range rate signal corresponding respectively to range and range rate to an immediately preceding lead vehicle;

wherein the range and range rate signals and a vehicle speed signal corresponding to said actual vehicle speed provide closed loop feedback to the headway controller, and the headway controller develops a speed reference signal which corresponds to the reference vehicle speed and provides a command signal input to the vehicle speed

control for causing the vehicle speed control to null discrepancy between said range to the immediately preceding lead vehicle as measured by the range signal and a reference range that varies with timed headway when the adaptive cruise control mode assumes a follow state;

and upon losing the track of the immediately preceding lead vehicle while said actual vehicle speed is less than the reference vehicle speed, the headway controller is operable to transition from the follow state of the adaptive cruise control mode to a resume state of the adaptive cruise control mode to return vehicle speed toward the reference vehicle speed as a function of lateral acceleration of the vehicle;

and wherein said function of lateral acceleration of the vehicle comprises attenuating gain of the resume function in an inverse relation to the magnitude of the lateral acceleration once the lateral acceleration has exceeded a predetermined minimum magnitude.

8. An automotive vehicle comprising:

a powertrain comprising an engine having a throttle that is selectively operated to apply an acceleration force to the vehicle via wheels on which the vehicle is supported and propelled along an underlying surface;

a vehicle speed control for selectively throttling the engine via the throttle to null discrepancy between actual vehicle speed and a reference vehicle speed;

a headway controller that is operable to different modes including an adaptive cruise control mode;

range and range rate apparatus for providing a range signal and a range rate signal corresponding respectively to range and range rate to an immediately preceding lead vehicle;

wherein the range and range rate signals and a vehicle speed signal corresponding to said actual vehicle speed provide closed loop feedback to the headway controller, and the headway controller develops a speed reference signal which corresponds to the reference vehicle speed and provides a command signal input to the vehicle speed control for causing the vehicle speed control to null discrepancy between said range to the immediately preceding lead vehicle as measured by the range signal and a reference range that varies with timed headway when the adaptive cruise control mode assumes a follow state;

and upon losing the track of the immediately preceding lead vehicle while said actual vehicle speed is less than the reference vehicle speed, the headway controller is operable to transition from the follow state of the adaptive cruise control mode to a resume state of the adaptive cruise control mode to return vehicle speed toward the reference vehicle speed as a function of lateral acceleration of the vehicle;

and wherein the speed reference signal comprises an algebraic summation of a term that is proportional to the vehicle's own speed as measured by the vehicle speed sensor, of a term that is proportional to the difference between the reference range and the range to the immediately preceding lead vehicle as measured by the range signal, and of a term that is proportional to range rate to the immediately preceding lead vehicle as measured by the range rate signal.

9. An automotive vehicle comprising;

a powertrain comprising an engine having a throttle that is selectively operated to apply an acceleration force to the vehicle via wheels on which the vehicle is supported and propelled along an underlying surface;

a vehicle speed control for selectively throttling the engine via the throttle to null discrepancy between actual vehicle speed and a reference vehicle speed;

a brake control system that is selectively operated to apply a deceleration force to the vehicle wheels;

range and range rate apparatus for providing a range signal and a range rate signal corresponding respectively to range and range rate to an immediately preceding lead vehicle; and

a headway controller that acts via the vehicle speed control for nulling discrepancy between said range to the immediately preceding lead vehicle obtained by the range and range rate apparatus and a reference range that varies with timed headway;

wherein the range and range rate signals and a vehicle speed signal corresponding to said actual vehicle speed provide closed loop feedback to the headway controller;

wherein the headway controller develops a reference speed signal which corresponds to the reference vehicle speed and provides a command input to both the vehicle speed control and the brake control system;

and the headway controller prevents the reference speed signal from causing the brake control system to apply deceleration force to the vehicle wheels whenever the range rate is positive.

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L7: Entry 6 of 7 File: USPT May 15, 2001

US-PAT-NO: 6233515
DOCUMENT-IDENTIFIER: US 6233515 B1

TITLE: Adaptive vehicle cruise control system and methodology

DATE-ISSUED: May 15, 2001

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FIELD-OF-SEARCH: 701/93, 701/94, 701/95, 701/96, 701/300, 701/301, 180/167-169, 180/176-179, 342/454, 342/455, 340/901, 340/903, 340/904, 340/435, 340/436

PRIOR-ART-DISCLOSED:

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Mayr, Intelligent Cruise Control for Vehicle Based ob Feed-back Linearization, Proceedings of the American Control Conference, US, New York, IEEE, Jun. 29, 1994, pp. 16-20, XP000515245, ISBN: 0-7803-1784-X.
Youcef-Toumi et al., The Application of Time Delay Control to an Intelligent Cruise Control System, Proceedings of the American Control Conference, US, New York, IEEE, Jun. 24, 1992, pp. 1743-1747, XP000343593, ISBN: 0-7803-0210-9.

ART-UNIT: 361

PRIMARY-EXAMINER: Chin; Gary

ATTY-AGENT-FIRM: Mollon; Mark L.

ABSTRACT:

Disclosed herein is a headway control for an adaptive cruise control system based on a basic headway control law derived from feedback linearization techniques. The usefulness of the linear approximations is demonstrated, and basic attributes of data which are believed important to system response are introduced. Certain modifications to a basic headway controller for enabling system performance to better meet driver expectations under real road conditions are made as a result of empirical information.

9 Claims, 8 Drawing figures